Preheat Loads Using Heat from Exhaust Gases for Industrial Heating Equipment

Prepared for California Energy Commission (CEC)

Prepared By:

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(A Sempra Energy Utility)

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Executive Summary

This work paper describes a calculator tool that will allow a user to estimate annual energy savings, associated cost savings (US Dollars), and CO_2 emission reductions through the use of preheated load or charge material, mentioned as "load" in this document, for industrial heating applications and boilers. The savings are estimated for a case where heat from flue (or exhaust) gases is used to preheat a load before its introduction into a process heating system (such as a furnace, oven, heater, dryer, melter, etc.). A special case of "load preheating" occurs when boiler feed water is preheated is discussed in a separate technical guide.

The thermal efficiency of a heating system can be improved significantly by using heat contained within furnace flue gases to preheat the furnace load. Allowing the direct contact of flue gasses and preheated material can be the best approach for capturing waste heat. Load preheating is best suited for continuous processes, but it can sometimes be used successfully with intermittently operated or batch furnaces. Load preheating can be achieved in a variety of ways, including the following:

- Use of an *unfired load preheat section*, in which furnace flue gases are brought in contact with the incoming load in an extended part of the furnace.
- Use of an *external box*, in which high-temperature furnace flue gases are used to dry and/or preheat the charge before loading in a furnace.

The "net" amount of energy savings obtained by using load preheating is *greater* than the amount of actual heat transferred to the load. The heat delivered to the load also needs to account for the efficiency of the furnace. Since the furnace efficiency is always less than 100%, the resulting energy savings exceeds the energy picked up by the load. Load preheating can result in higher production rates from the same furnace without significant modifications.

This calculator estimates the annual expected energy savings in terms of million British thermal units per year (MM Btu/year). It also estimates energy cost reduction using a given cost of energy used for the application and number of operating hours per year. This calculator gives the reduction in CO_2 emissions resulting from reduced natural gas consumption. Primary objective of this calculator is to promote energy savings in industrial heating operations and allow a user to calculate potential savings that can be used to make a go/no go decision on additional detailed engineering and economics analysis. The user is required to give data or values for several operating parameters that can be measured or estimated during the average operating conditions using available records or actual measurements. The data should be collected at typical or average operating conditions. Accuracy of the results is expected to be within plus or minus 5 percent.

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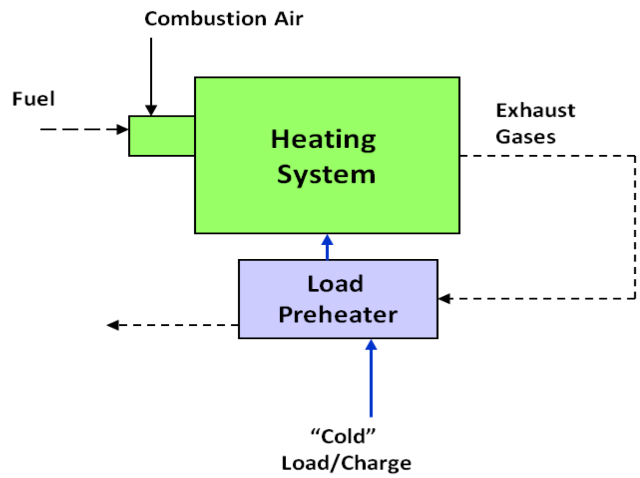
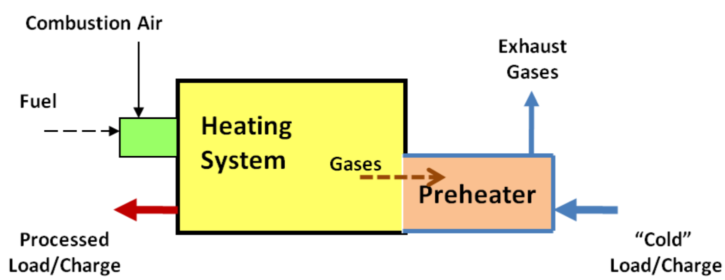
LIST OF EXHIBITS

1. Description of the topic or subject area

This technical guide describes a calculator tool that will allow the user estimate annual energy (fuel) savings, reduction in CO_2 emissions, and energy cost savings ($/year) with use of preheated load or charge material in a heating equipment (furnace, oven, heater, melter, dryer etc.). This calculator covers the specific case when a load is heated through direct contact with the flue gasses before it is charged into the heating equipment. The hot exhaust gases will transfer a part of their heat content into the load, resulting in lower exhaust gas temperature from the system, while raising temperature of the load. In some cases, it is possible to use load preheating to remove moisture from the load in addition to raising the temperature. Load preheating decreases the heat requirement in the heating system and results in an improved thermal efficiency and correlating reduction in energy intensity (energy use per unit of production). A schematic depiction of two commonly used methods of load preheating is shown in Exhibit 1.



1. Use of external load preheater



2. Use of integral load preheater

Exhibit 1: Two commonly used methods of load preheating

In Case 1 the exhaust gases are directed to a separate preheater system where the load is preheated by using heat from the exhaust gases. In this case the "cold" load is preheated before being physically taken to the heating system and charged at a higher temperature. In Case 2 the existing furnace is modified to add an "unfired" preheat zone or chamber that allows the flue gases or combustion products from the furnace firing zone to come into contact with the load. Heat from the furnace is transferred by convection from the gases and radiation from the preheat zone walls to raise temperature of the load before it enters the main furnace. In both cases, the exhaust gas temperature is reduced and more heat is retained within the system. This results in higher thermal efficiency for the heating system.

The calculator estimates the expected annual energy savings when the furnace[1] operating conditions are known. The focus of this technical guide's discussion is on industrial heating processes using a load preheating system to transfer heat from flue gases to the load. Industrial boilers can also utilize load preheating by using flue gas heat for feed water heating in a device commonly known as an economizer. A separate calculator has been developed to estimate energy savings in boilers with use of an economizer.

The calculator requires specific measured data related to the current furnace performance and cost of energy (in terms of $/MMBtu). The effect of the change in the material's load temperature is reported under the "modified" conditions and details changes in the furnace energy consumption, CO_2 emissions, and cost savings. The data requirements are discussed in a following section.

The results are calculated using natural gas as the main fuel and are considered a good representation of the energy savings within a limited range of natural gas compositions. The results are also considered as good approximation for other hydrocarbon gaseous fuels. Large amounts of inert gases such as nitrogen (N_2), water vapor (H_2O), and carbon dioxide (CO_2) can invalidate results. It is necessary to give a detailed description of the fuel gas composition when such fuels are used. We do not recommend use of this calculator when fuel composition is considerably different from the commonly used natural gas in California. Use of additional engineering or expert help is recommended for such cases.

The calculation methodology and equations used are based on the output of equilibrium combustion models and tables of physical properties. They are approximations analogous to the calculation results of the Process Heating Assessment and Survey Tool (PHAST)[2].

2. Impact of the energy saving measure (activity) on energy savings, CO_2 reduction, and water consumption reduction, if any.

This calculator allows a user to estimate energy savings that can be achieved when the load is heated by using heat from the exhaust gases from a furnace. All commonly used fossil fuels such as natural gas result in reduction of formation of CO_2. The amount of CO_2 emissions reduced is directly proportional to the reduction in consumption of natural gas.

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[1] In this Technical Guide , the term "furnace" is frequently used as convenient shorthand for the more precise "process heating equipment (furnace, oven, kiln, heater, etc.) or process boiler".

[2] The PHAST model was developed as part of a formal partnership agreement between the Department of Energy and the Industrial Heating Equipment Association. Dr. Arvind Thekdi, E3M, Inc. was the project manager for the development of PHAST and has provided the program logic for the calculators under a separate contract to the Gas Company.

The calculator is designed to give results assuming that the process uses natural gas as fuel. The actual savings in fuel consumption and associated energy costs depend on several operating parameters. They include:

- Load or charge material, its specific heat, moisture content (if any), and charging rate per hour
- Load temperature as it enters the furnace before and after implementation of load preheating
- Temperature of exhaust gases leaving the furnace
- Amount of oxygen (on dry basis) in exhaust gases
- Temperature of combustion air for the burners
- Number of operating hours per year
- Current fuel usage for the furnace
- Cost of fuel in terms of ———

The energy savings can vary from 5% for low temperature processes to as high as 30% for high temperature processes.

The CO_2 savings are directly related to energy savings. According to the U.S. Environmental Protection Agency (EPA) estimates (Reference 5), combustion of natural gas used in USA, produces 116.39 lbs. of CO_2 for every one million Btu of heat input. For convenience most calculations use 117 lbs of CO_2 emission per million Btu of heat input from natural gas. If the natural gas composition is available, it is advisable to carry out detail combustion calculations to estimate actual amount of CO_2 produced by the combustion of natural gas. Reduction in CO_2 emission is calculated by using value of reduction in energy (heat) used for the furnace.

Annual energy cost savings depend on the cost of energy (expressed as Dollars per MM Btu) and energy savings estimated using the calculator.

3. Discussion on the technical approach and the calculations

The energy savings and associated CO_2 emission reduction are calculated for natural gas. The savings are calculated for a system in which heat from exhaust gasses are used to preheat load as shown in Exhibit 1. In these calculations it is assumed that the system heat losses excluding flue gas losses and heat absorbed by the load remain constant. Example of such losses include: wall loss, cooling loss, opening losses, and other losses that are primarily dependent on the process or furnace zone temperature. These losses should remain constant when load preheating is used.

The savings are based on changes in the amount of heat required for the load. In most cases, energy savings results from a reduction in rise of sensible heat required for processing and/or a reduction in moisture content in the load (if present). The actual reduction in heat consumed by the heating system or furnace is greater than the calculated value of reduction in heat requirement for the load since this value has to include a correction for available heat.

The term available heat is defined as difference between the amount of heat input and the amount of heat contained within the exhaust gases leaving the furnace system. It is usually expressed as percentage (%) and represents the amount of heat remaining in a furnace as a fraction or percentage of the heat input to the furnace.

However the total heat input

Note that H_f is total heat demand within the furnace and it includes the heat required for the load and losses such as wall loss, opening loss, fixture heat requirement, cooling losses etc. Not all losses are present in all furnaces.

Available heat expressed in terms of percentage is given as

Where

= Furnace heat demand

= Available heat (%)

= heat input in the furnace (Btu/hr)

= heat content of exhaust gases leaving the heating system or furnace (Btu/hr)

= Percent available heat

The value of available heat percentage ( ) of the heat input depends on four major parameters: flue gas temperature, fuel composition, excess air contained within the flue gases, and combustion air temperature used for the burners.

In most cases load preheating does not change the flue gas temperature exiting the main furnace section. Note that we do not say that the flue gas temperature coming out of the heating system that includes the preheater recons constant. Hence it is safe to assume that available heat remains practically constant

Consider two cases: one where the load temperature entering the furnace is lower and one where the load is preheated. The furnace heat demand in each case can be stated as and .

Difference between and is due to reduction in heat demand for eh load. The heat demand for a load changes as additional heat is required to raise temperature of the load and to vaporize/superheat water from the load to the exhaust gas temperature when water is present.

Thus the heat requirement for load can be stated as:

can include sensible heat, heat of malign, superheating of molten material etc., while includes heat required to evaporate water and superheat the steam produced from the water.

In most cases during load preheating the load temperature is raised but maintained below melting point. The water content can often be reduced significantly or eliminated.

In this calculator we have assumed that load is not melted prior to charging it into the main furnace section and water content of the load may or may not change during load preheating.

With use of preheated combustion air, we can consider two different operating conditions. One in which the combustion air is temperature low (T_{ac}) and another where combustion air temperature is higher (T_{ah}). Correspondingly the heat input will be H_{inc} and H_{inh}, and the available heat will be $Avht_c(\%)$ and $Avht_h(\%)$. Note that in each case the furnace heat demand is constant at H_f. For each case heat content is H_{exc} and H_{exh} respectively.

Hence

As mentioned earlier the available heat (Avht(%)) depends on the following variables:

- Fuel composition
- Exhaust gas temperature
- Combustion air temperature
- Percent Oxygen (dry) in the exhaust gases.

Available heat can be calculated by using combustion calculations for a given fuel using the Preheated Combustion Air Tool. The tool calculations use a typical natural gas composition found in California listed in Exhibit 2.

Fuel Gas Analysis (See note below)		
Gas composition	**By volume**	**Adjusted by volume**
CH4	**94.00%**	**94.009%**
C2H6	**2.07%**	**2.070%**
N2 and other inert	**1.50%**	**1.500%**
H2	**0.01%**	**0.010%**
C3H8	**0.42%**	**0.420%**
C4H10 + CnH2n	**0.28%**	**0.280%**
H2O	**0.00%**	**0.000%**
CO	**1.00%**	**1.000%**
CO2	**0.71%**	**0.710%**
SO2	**0.00%**	**0.000%**
O2	**0.00%**	**0.000%**
Total of fuel components	**99.99%**	**100.000%**
Difference	0.01%	0.00%

Note: The fuel gas composition is in volume %. The higher hydrocarbons in fuel are treated as same as C4H10 and all other inert gases are treated as N2.

Exhibit 2: Composition of natural gas used or calculations.

For this calculator, the higher heating value of a fuel is used. The higher heating value for natural gas with the composition shown in Exhibit 2 is 1,011 Btu/scf. While natural gas heating value may vary from as low as 970 Btu/scf to as high as 1,200 Btu/scf. Approximately 1,000 Btu/scf is considered the nominal heating value of natural gas.

It is recognized that the natural gas composition may vary based on time of year and location. However, a series of calculations show that variation in natural gas composition has very small effect on available heat (expressed as a percentage of the heating value). Hence, available heat changes are within a narrow range and error in its value is relatively small (±5%). In this case, we advise the user that the accuracy of the estimate will be in the same order of magnitude (±5%) with use of this calculator. A separate calculator is available to calculate the exact value of available heat when the fuel composition is known and is significantly different from the composition stated in Exhibit 2.

Further discussion on available heat and the effect of fuel is discussed in References 1 and 2.

The magnitude of reduction in energy or heat used for a furnace with use of preheated load can be estimated by calculating using changes in heat requirement for the furnace and knowledge of available heat.

Annual savings can be expressed in terms of Btu/year, Therms / year, or Million (MM) Btu/year by using appropriate equations given below.

The CO_2 savings can be calculated by using the fuel combustion calculations or by using the EPA guidelines for CO_2 generation calculations. Reference 5 gives details of US EPA guidelines.

4. Instruction on use of each calculator.

The following list summarizes the user inputs that are required. The user should collect this information before use of this calculator-tool.

- Company name, plant location and address
- Customer name and contact information
- Heating equipment description (where the energy saving measure is applied)
- Equipment type (furnace, oven, kiln, heater, boiler)

- Equipment use (e.g., textile drying, aluminum melting, food processing.)

Note that some of this information may be optional for the web based calculators due to user's concerns about privacy.

- Charge material
- Charging rate – as charged dry (lbs/hr)
- Charge Initial temperature (°F)
- Specific heat of the charge in temp. range of preheat (Btu/lb°F)
- % water in the charge (use water weight as % of dry charge)
- Flue gas temperature from oven/furnace (°F)
- Combustion air preheat temperature (°F)
- Percent O2 in flue gases (%)
- Energy (fuel) Cost ($/MM Btu)
- Number of operating hours (hrs./per year)

The calculator gives following results.

- Net heat reduction due to preheat (Btu/hr)
- Available heat (%)
- Savings in total heat supplied to oven/furnace (MM Btu/hr)
- Annual energy savings (MM Btu/year)
- Savings in annual energy cost ($/year)
- Reduction in CO_2 emission (tons/year)

Note that the CO_2 savings are based on use of natural gas as fuel for the heating equipment. A correction factor must be applied if any other fuel is used.

The combustion air preheating calculator requires following input parameters to describe the user and to estimate the savings. Exhibit 3 shows the user information screen and Exhibit 4 shows the calculator screen.

The first section requires information for the user, the equipment, process etc.

Preheat Loads using Heat from Exhaust Gases (Calculator for Furnace Charge Preheating using Exhaust Gases)					
1	Company name	ABC Corporation			
2	Plant name or designation	LA Plant			
3	Plant address	12345 Main Street, Gabriel, CA 90878			
4	Contact name	Bob Smith			
5	Contact address	54321 First Street, North Warren, CA 90878			
6	Contact phone number and e-mail	Phone:	916-756-9923	Email:	b.smith@abccorp.com
7	Date (format mm/date/year)	May 12, 2010			
Heating equipment description (where the energy saving measure is applied)					
8	Equipment type (e.g. furnace, oven, kiln, heater, boiler)	Furnace			
9	Equipment use (e.g., textile drying, aluminum melting)	Gas fired furnace			
10	Other comments if any	The furnace exhaust gases are dischrged from a single stack			

Exhibit 3: Required information for the calculator user

Line 1 – Name of the company

Line 2 – Name or known designation such as “main plant” or “secondary plant” if applicable

Line 3 – Plant address

Line 4 – Contact name for the plant. This is the individual who is main contact and responsible for collecting and providing the required data or information.

Line 5 – Address for the contact person

Line 6 – Contact phone number and e-mail to be used for all future communications

Line 7 – Date when the calculations are carried out

Line 8 –Type of heating equipment – This can be an oven, a furnace, a boiler, heater etc. heating equipment where data is collected and the given energy saving measure is to be applied.

Line 9 – Process or function for which the heating equipment is used. This can be name of the process such as drying, melting, water heating etc.

Line 10 – Additional information.

The second section of the calculator is used for collecting the necessary data and reporting the estimated savings.

There are two columns for the calculator. The "Base" column represents the current conditions or data collected as average values for each of the parameters. Details of the data are given below. Data for the "New" conditions represents values of each of the inputs after the suggested measure (use of preheated load material) is implemented.

Calculations for Savings - Furnace Charge Preheating using Exhaust Gases			
		Base	**New**
11	Charge Material	Aluminum	
12	Charging rate (as charged with moisture) (Lbs./hr)	4,000	
13	*Base* Charge Initial temperature (°F)	82	
14	*New* Charge Preheat temperature (°F)		400
15	Specific heat of the charge in temp. range of preheat (Btu/lb. F)	0.21	0.21
16	*Base* % moisture content in the charge (cold)	1.00%	
17	*New* % moisture content in the charge (preheated)		0.25%
18	Net heat reduction due to preheat (Btu/hr)	300,269	
19	Flue gas temperature from oven/furnace (°F)	1100	1100
20	Air preheat temperature (°F)	80	80
21	Current O2 in flue gases (%)	6.00	6.00
22	Available heat (%)	60.85%	60.85%
23	Savings in gross heat supplied to oven/furnace (Btu/hr.)	Base	493,475
24	Total energy savings (MM Btu/hr)	Base	0.493
25	Energy Cost ($/MM Btu)	$8.00	$8.00
26	Operating Hrs (per year)	8000	8000
27	**Energy savings (MM Btu/year)**		**3,948**
28	**Savings - Energy cost ($/year)**	**Base**	**$31,582.37**
29	**CO2 savings based on fuel:natural gas(tons/year)**		**231**

Exhibit 4: Example of calculator inputs and results

Line 11 – Charge material – The name of the material charged in the furnace.

Line 12 – Charging rate – as charged with moisture (lbs/hr) – The rate for wet material charged in the furnace.

Line 13 – Base charge initial temperature (^{o}F) – The temperature of the charge material entering the main furnace section. For base conditions, this value will be temperature reading of the material before implementation of preheating.

Line 14 – New charge initial temperature (^{o}F) – The future temperature of the charge material entering the main furnace section.

Line 15 – Specific heat of the charge in temperature range of preheat. (Btu/lb^{o}F) – The specific heat can be obtained from a table given as a link to the calculator. This table is also reproduced in Appendix 1. The specific heat of a material changes with temperature and it is necessary to use an averaged value at a mean temperature between the current temperature and expected preheat temperature. The table given does not attempt to give precise values for all temperature ranges. Values from this table are to be used as a first approximation to estimate energy savings. If necessary, contact the material supplier or consult other sources (handbooks, supplier literature etc.) to determine more accurate values. Reference 1 can be used to get temperature dependent value for commonly used metals.

Line 16 – Base % moisture content in the charge (cold)– Give the % of moisture content within the charged material as a percentage of dry charge. If the weight of water content is known then it should be used to calculate % moisture. The formula to use is:

If the moisture analysis is available (in terms of wet charge material), then use following formula to calculate the percent moisture of the dry charge rate.

Line 17 – New % moisture content in the charge (preheated) – Give the % of moisture content within the charged material as a percentage of dry charge.

Line 18 – Net heat reduction due to preheat (Btu/hr) – This is a calculated value. It represents reduction in the amount of heat required to raise the material to the process temperature. It assumes that no residual moisture is left in the material as it leaves the main furnace. While it is still possible that not all moisture is removed during preheat, all moisture is removed when the material is discharged from the furnace.

Line 19 – Flue gas temperature from oven/furnace (°F) – Give the flue gas temperature as measured as close to the exit of the furnace as possible. Note that when preheating is done in an extended furnace section or unfired preheat section, this represents flue gas temperature coming out of the furnace and entering the preheat section. Obtain flue gas temperature measurements as close to the exit of the furnace as possible. The flue gas temperature should be taken when the furnace is operating at normal operating conditions from the middle of the stack. Measuring the temperature at the top of the stack or very close to the wall of the discharge duct can give erroneous reading.

Readings taken at non-average production or operating conditions can give unreliable results. Make sure that the flue gases are NOT mixed with cold air before the temperature is measured. Note that in almost all cases the flue gas exit temperature does not change when using load preheating since the furnace zone temperatures are controlled to meet the required process conditions.

Line 20 – Combustion air preheat temperature (°F) – The temperature of combustion air entering the burners. In many cases it is not feasible to obtain exact air temperatures at the burner. A common practice is to use air temperature entering the combustion air blower or ambient temperature as the combustion air temperature if no air preheater is installed. If an air preheater is installed, use the air temperature exiting the recuperator or entering the burner.

Line 21 – Percent oxygen (O_2) in flue gases (%) – This value is obtained from a flue gas analysis using commonly available flue gas analyzers. These analyzers give measurements of flue gas components on dry basis in addition to other. The gas analysis sample should be taken when the furnace is operating at normal operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. It is necessary to make sure that the flue gases are not mixed with cold air before the temperature is measured. Care should be taken to locate the sampling probe in the middle of the stack or area from where the flue gases are discharged.

Line 22 – Available heat (%) – This is a calculated value based on the data given above. The calculation uses the "Available Heat" tool developed as part of this tool set and uses natural gas as fuel. The natural gas composition used for this calculation is same as given in Exhibit 2.

Line 23 – Savings in gross heat supplied to oven/furnace (MM Btu/hr) – This is a calculated value. It is the original heat input compared to the reduction in burner heat input with use of load preheating. It is obtained by dividing net heat reduction calculated in Line 16 above by the percentage available heat.

Line 24 – Total energy savings (MM Btu/hr) – This is a calculated value. It is the total energy saved by load preheating in MM Btu/hr.

Line 25 – Energy (fuel) cost ($/MM Btu) – This is the cost of fuel expressed in terms of $/MM Btu. The cost should include all charges related to use of fuel at "the burner tip". This value can be obtained from the monthly or annual gas bill or by dividing the total annual cost by the annual fuel used.

Line 26 – Number of operating hours per year (hrs/year) – This represents the annual operating hours at the average firing conditions given above.

Line 27 – Energy savings (MM Btu/year) – This gives estimated annual dollar savings resulting from reduced cost of fuel. It does not include any other savings or costs (negative savings) associated with use of preheated load. In most cases any other savings or costs are small and often ignored. This is a calculated value for annual energy savings based on savings in total heat supplier per hour (Line 21) and number of operating hours per year (Line 23).

Line 28 – Savings - energy cost ($/year) – This is a calculated value for savings in energy cost per year based on annual energy savings (Line 24) and fuel cost (Line 22).

Line 29 – Reduction in CO_2 emission (tons/year) – The savings are calculated based on annual fuel savings assuming the fuel is natural gas. The savings are in Short (or US) tons and not in Metric tons.

1. References

1. *North American Combustion Handbook*, Third Edition, 1986. Published by North American Mfg. Company, Cleveland, OH.
2. *Combustion Technology Manual*, Fifth Edition, 1994. Published by Industrial Heating Equipment Association, Cincinnati, OH.
3. *Improving Process Heating System Performance: A Sourcebook for Industry*, U.S. Department of Energy and Industrial Heating Equipment Association. Available on-line at www.eere,eenrgy.gov/industry.
4. *Tip sheets and Technical Briefs*, published by The U.S. Department of Energy. Available on-line at www.eere,eenrgy.gov/industry.
5. *Unit Conversions, Emission Factors and Other Reference Data, published by the U.S. EPA, November 2004. Available on-line at http://www.epa.gove/cpd/pdf/brochure.pdf*

Appendix

Average Specific Heat for Commonly Processed Materials

Material	Specific Heat Capacity* - cp -	
	(Btu/lb$_m$ ^{o}F) (kcal/kg ^{o}C)	(kJ/kg K)
Aluminum, 0^{o}C	0.21	0.87
Antimony	0.05	0.21
Apatite	0.20	0.84
Asbestos cement board	0.20	0.84
Asbestos mill board	0.20	0.84
Ashes	0.20	0.84
Asphalt	0.22	0.92
Augite	0.19	0.80
Bakelite. wood filler	0.33	1.38
Bakelite. asbestos filler	0.38	1.59
Barite	0.11	0.46
Barium	0.07	0.29
Basalt rock	0.20	0.84
Beeswax	0.82	3.40
Beryl	0.20	0.84
Bismuth	0.03	0.13
Bone	0.11	0.44
Borax	0.24	1.00
Boron	0.31	1.30
Brass	0.09	0.38
Brick, common	0.22	0.90
Brick, hard	0.24	1.00
Cadmium	0.06	0.25
Calcite 32 - 100F	0.19	0.80
Calcite 32 - 212F	0.20	0.84
Calcium	0.15	0.63
Carbon, Diamond	0.12	0.52
Carbon, Graphite	0.17	0.71
Carborundum	0.16	0.67
Cassiterite	0.09	0.38
Cement dry	0.37	1.55
Cement powder	0.20	0.84
Charcoal	0.24	1.00
Chalk	0.22	0.90
Chalcopyrite	0.13	0.54
Charcoal, wood	0.24	1.00
Chromium	0.12	0.50
Clay	0.22	0.92
Coal, anthracite	0.30	1.26
Coal, bituminous	0.33	1.38
Cobalt	0.11	0.46
Coke	0.20	0.85

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Material	Specific Heat Capacity* - cp -	
	($Btu/lb_m\,^oF$) *($kcal/kg\,^oC$)*	*(kJ/kg K)*
Concrete, stone	0.18	0.75
Concrete, light	0.23	0.96
Copper	0.09	0.39
Corkboard	0.45	1.90
Corundum	0.10	0.42
Diamond	0.15	0.63
Dolomite rock	0.22	0.92
Earth, dry	0.30	1.26
Fiberboard, light	0.60	2.50
Fiber hardboard	0.50	2.10
Firebrick	0.25	1.05
Fluorite	0.22	0.92
Fluorspar	0.21	0.88
Galena	0.05	0.21
Garnet	0.18	0.75
Glass	0.20	0.84
Glass, crystal	0.12	0.50
Glass, plate	0.12	0.50
Glass, Pyrex	0.18	0.75
Glass, window	0.20	0.84
Glass, wool	0.16	0.67
Gold	0.03	0.13
Granite	0.19	0.79
Graphite	0.17	0.71
Gypsum	0.26	1.09
Hairfelt	0.50	2.10
Hermatite	0.16	0.67
Hornblende	0.20	0.84
Hypersthene	0.19	0.80
Ice 32^{o}F (0^{o}C)	0.49	2.09
India rubber min	0.27	1.13
India rubber max	0.98	4.10
Iridium	0.03	0.13
Iron, 20^{o}C	0.11	0.46
Labradorite	0.19	0.80
Lava	0.20	0.84
Limestone	0.20	0.84
Lead	0.03	0.13
Leather, dry	0.36	1.50
Lithium	0.86	3.58
Magnetite	0.16	0.67
Malachite	0.18	0.75
Manganese	0.11	0.46

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Material	Specific Heat Capacity* - cp -	
	(Btu/lb $_m$ °F) *(kcal/kg °C)*	*(kJ/kg K)*
Magnesia (85%)	0.20	0.84
Marble	0.21	0.88
Mercury	0.03	0.14
Mica	0.12	0.50
Mineral wool blanket	0.20	0.84
Oliglocose	0.21	0.88
Orthoclose	0.19	0.80
Paper	0.33	1.40
Paraffin wax	0.70	2.90
Peat	0.45	1.88
Plaster, light	0.24	1.00
Plaster, sand	0.22	0.90
Plastics, foam	0.30	1.30
Plastics, solid	0.40	1.67
Platinum, 0°C	0.03	0.13
Porcelain	0.26	1.07
Potassium	0.13	0.54
Pyrex glass	0.20	0.84
Pyrolusite	0.16	0.67
Pyroxylin plastics	0.36	1.51
Quartz mineral 55 - 212°F	0.19	0.80
Quartz mineral 32°F (0°C)	0.17	0.71
Rock salt	0.22	0.92
Rubber	0.48	2.01
Salt	0.21	0.88
Sand	0.19	0.80
Sandstone	0.22	0.92
Sawdust	0.21	0.90
Serpentine	0.26	1.09
Silica aerogel	0.20	0.84
Silk	0.33	1.38
Silver, 20°C	0.06	0.23
Sodium	0.30	1.26
Soil, dry	0.19	0.80
Soil, wet	0.35	1.48
Stone	0.20	0.84
Stoneware	0.19	0.80
Sulphur	0.17	0.71
Tar	0.35	1.47
Tellurium	0.05	0.21
Tile hollow	0.15	0.63
Topaz	0.21	0.88
Tungsten	0.04	0.17
Vanadium	0.12	0.50
Vermiculite	0.20	0.84
Vulcanite	0.33	1.38
Wood, balsa	0.70	2.90
Wood, oak	0.48	2.00
Wood, white pine	0.60	2.50
Wool, loose	0.30	1.26
Wool, felt	0.33	1.38